Agricultural Supply Chains under Government Interventions

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The agricultural sector, especially in developing economies, is subject to uncertainties that may adversely affect farmers' yields and realized incomes. Government support is often used to ensure steady incomes for the farmers and a reliable supply of agricultural commodities. We study a regional market with a population of farmers subject to random yield serving a continuum of consumers. We investigate the effectiveness of three types of interventions, price support, cost support, and yield enhancement efforts, as well as different policy implementation methods such as announcing the total budget or the unit support, in terms of their impact on farmers' incomes, consumer surplus, and return on government spending. It is shown that price and cost support interventions are equivalent if the total budget is public information. On the other hand, if the government announces the unit support, the benefit to different stakeholders along the agricultural supply chain depends on the market distortion created by the intervention. Specifically, in this case, price support results in greater distortion, benefiting consumers more than cost support whereas the converse holds for farmers. Furthermore, we find that under yield enhancing efforts, farmers may incur losses due to the interplay of several market and crop characteristics. Lastly, we show that interventions cannot always generate positive return from the government's perspective.

Key words: government interventions; subsidies; agricultural supply chains

1. Introduction

Even though agriculture is an important sector around the world, its role in the economy is especially significant in developing countries where farmers constitute a large portion of the population. In developing nations, the majority of the farmers are small and struggle with financial constraints, causing them to be vulnerable to the income risk mainly resulting from the uncertainty in the yields and prices. A considerable portion of the consumers also live on low incomes, experiencing difficulty in access to affordable food. As a result, it is common for the governments to intervene in the agricultural sector with the goal of supporting farmers’ incomes and ensuring food security for
the consumers. Such government interventions may result from the political pressure exerted by the farmers as in the case of India where almost half of the population is employed in agriculture, the government’s long-term food policy such as the goal of achieving self-sufficiency in rice production in the Philippines and Indonesia, or as in China’s case, the motivation may be to maintain food security by preventing farmers from abandoning their land.

Irrespective of the root cause, governments invest substantial resources in agricultural interventions. China’s expenditure in farming subsidies surged from $17.91 billion in 2000 to $103.94 billion in 2012 and India reached $13.41 billion in agricultural spending in 2011 (IFPRI 2015). A considerable portion of agricultural spending in these countries is dedicated to subsidies as well as price support programs that aim to protect farmers against the price risk by guaranteeing a minimum support price. The Chinese government offers support prices for various crops including wheat, corn, soybeans, rice, and cotton. From 2007 to 2012, the support price for rice was more than doubled and the wheat support price was raised by 70% (Gale 2013). In the Philippines, where 30.4% of employment is in agriculture, rice is the staple food and food security is mainly associated with the availability of affordable rice (The World Bank 2016). National Food Authority (NFA), a corporation owned and controlled by the Philippine government, aims to ensure food security through the stabilization of rice supply and price, and offers price support to palay (unmilled rice) farmers for protection against the instances with low market price (Bordey and Castaneda 2011). The counterpart of NFA in Indonesia is the Bureau of Logistics (BULOG), which implements price floor for palay farmers in order to promote rice production and attain self-sufficiency in rice (Sidik 2004).

Along with price support programs, cost support policies such as input subsidies, which are used to support farmers’ incomes by reducing production costs, are also widely used in many countries. In fact, subsidies constitute 17% of total farm income in China according to the Economist (2015), and 13% of the country’s agricultural expenditure is on input subsidies (Yu et al. 2014). Similarly, in India, the government heavily subsidizes inputs such as fertilizers, electricity, and irrigation (Grossman and Carlson 2011, Fan et al. 2007). Indonesia also uses agricultural input subsidies extensively in order to achieve rice self-sufficiency. In fact, in 2009, fertilizer subsidies alone accounted for 37% of the total support for agriculture (Warr and Yusuf 2014). Additionally, in the Philippines, as part of the hybrid rice commercialization program, the government allocated more than PhP 6 billion (~ $128 million) for various input subsidies as well as the procurement of hybrid seeds from 2001 to 2005 (David 2006).

Lastly, a boost in production can be achieved through governments’ supporting various yield enhancing efforts. Investment in research and development practices in order to increase seed
varieties, seed resistance to pests or availability of high yielding seeds is one example of such interventions. Another way of increasing farm yields is to educate farmers on efficient farming practices and/or effective use of machinery and fertilizers. These methods are different from the intervention types mentioned earlier in that farmers do not receive direct payments from the government but instead, experience an increase in productivity due to the intervention. Lately, some countries have been allocating more resources to yield enhancement efforts as other policy instruments including input subsidies and price support are criticized for causing distortions in farmers’ production quantities due to the acreage or output-contingent payment schemes. For instance, China is increasing focus on the interventions that aim to modernize agriculture and increase productivity (Gale 2013). Furthermore, India’s poorest state, Bihar, has been investing in educating small rice farmers on a growing method called System of Rice (Root) Intensification that has resulted in a significant increase in farm yields (Vidal 2013). The hybrid rice commercialization program implemented in the Philippines in early 2000s aimed to increase the yields in rice production through the use of high-yield hybrid seeds.

Given that governments allocate significant amount of resources to the widely used agricultural policy instruments described above, it is essential to examine if the intended impact can be achieved through these policies. Also, since there is criticism about interventions’ role in distorting farmers’ production decisions, resulting in overproduction and abuse of land use, it is not clear if these policies benefit the general public or just favor the producer population who may have some power over policy makers for political reasons. Thus, in this paper, we examine the price and cost support policies as well as yield enhancement efforts in terms of their impact on different parties along the agricultural supply chain, namely the farmers, the consumers, and the government. Specifically, we study how the surplus generated through these policies is distributed between the farmers and the consumers. The policy maker’s perspective is also taken into account by studying the return on government spending as it is desirable for the policy maker to achieve the intended benefit to farmers and/or consumers while maintaining a positive overall return by implementing a policy mechanism that creates a shift in the market equilibrium. Otherwise, despite the benefit to the general public, the intervention may not be rewarding from the government’s perspective. To the best of our knowledge, this approach in analyzing the effectiveness of policy instruments has not been studied in the literature, so we aim to contribute to the research on public policy by formulating the conditions under which interventions can create added value in excess of the monetary investments by the government.

We use a single-period model with a population of farmers subject to random production yield serving a continuum of consumers with heterogeneous valuations. In this setting, farmers engage in Cournot competition in that they choose how much land to allocate to production. On the consumer
side, the demand function is shaped by the market price and consumers’ willingness to pay. Once the yield is realized, determining the total supply, the market price ensures market clearing. Under this setting, we analyze price and cost support interventions under two implementation methods. The first one entails the government’s signaling information about the total budget allocated to the intervention such as the Chinese government’s announcement of exercising a 20% budget cut for input subsidies allocated to small farmers (Su 2015). The second method entails the announcement of the support price or the unit subsidy guaranteed by the government to the farmers, which is often undertaken in the case of long-term policy implementation in order to achieve a specific goal such as NFA’s guarantees on the support price provided to the farmers in order to achieve self-sufficiency in rice production in the Philippines. For price and cost support interventions, we discuss the differences in the outcomes of these two implementation methods. On the other hand, yield enhancing efforts are often announced in the central or local government’s development plans by disclosing the amount of budget allocated to a specific initiative and the yield increase that is expected to be obtained. Thus, under the yield enhancement intervention, we only focus on the case in which the farmers are notified about the expected improvement in yield.

Under this setting, we rank the price and cost support interventions under different implementation processes in terms of the induced market distortion. We find that the price support policy with the announcement of the support price causes the highest distortion in farmers’ production quantities whereas announcing the total budget under both price and cost support policies results in the least distortion. Under the same government expenditure, higher market distortion benefits the consumers due to the surge in supply and reduction in price whereas farmers are better-off under interventions that cause less overproduction. As a result, less aggressive policies in terms of the incentives provided to farmers to boost production, such as price/cost support with the budget announcement, result in a higher beneficial impact on farmers’ profits whereas more aggressive policies that cause substantial market distortion, such as the price support policy with the announcement of the minimum guaranteed price, achieves a greater impact on the consumer surplus. The cost support policy with the announcement of the unit subsidy lies in between the two extremes and attains equity in the percent increase in the welfare of both parties. We find that the policy maker cannot always obtain positive return through these interventions. In fact, the government surplus is negative for a larger set of expenditure values for policies that cause higher market distortion. As government spending increases, high-distortion interventions become more detrimental as the incentives that cause overproduction are inflated, which in turn results in lower social welfare and government surplus compared to low-distortion interventions. In light of our findings, we discuss that the use of fertilizer subsidies in Indonesia is less effective in terms of boosting rice production compared to the price support policy with the announcement of the guaranteed
minimum price implemented in the Philippines considering the goal of achieving rice self-sufficiency common to both countries. However, given the same expected government expenditure, Indonesia can generate higher benefit to farmers through fertilizer subsidies, and also attain higher social welfare if the expected expenditure is high enough. Finally, in the case of yield enhancing efforts, we find that even though consumers benefit from the increased productivity, farmers may not due to the interplay of several market and crop characteristics. In some cases, the negative effect of the yield improvement in the form of an increase in competition can exceed the benefit from increased productivity, causing a reduction in farmers’ profits.

The rest of the paper is structured as follows. Section 2 presents the related literature. We describe the model formulation in Section 3 and the interventions are studied in Section 4. Section 5 presents the concluding remarks.

2. Related Literature
Our paper contributes to several branches of literature that study agricultural supply chains and the role of public policy in agriculture. We refer the reader to Sumner et al. (2010) for an extensive review of the research on policy analysis in the agricultural economics literature. Most of these papers employ empirical methods to estimate the impacts of various policy instruments in different countries. Dardis (1967) investigates the price support policy in the U.K. and estimates the welfare cost due to the distortions in production and consumption caused by the policy. Lichtenberg and Zilberman (1986) estimate the welfare effects of introducing a productivity-decreasing regulation in the presence of a market-distorting price support policy using data on corn, cotton, and rice from the U.S. market. Demirdogen et al. (2016) investigate two policy instruments, output support and input support, using farm-level data from Turkey, and find that input support policies have a stronger effect on farmers’ land allocation decisions compared to output support policies. Contrary to this finding, our results indicate that the price support policy when the government announces the support price causes greater distortion in the amount of land allocated to production compared to the cost support policy (both under the budget or the unit subsidy announcement) keeping the expected government expenditure fixed. In our model, the market price is affected by the policy instrument through the change in farmers’ allocation decisions whereas Demirdogen et al. (2016) treats price as an exogenous variable in the estimation, causing the difference in the results. Related to our motivational example of the policies implemented in the Philippines, Barker and Hayami (1976) study price support and input subsidy interventions using data from the Philippine rice economy and show that subsidies applied to fertilizers can be more efficient in terms of the benefit-cost ratio than price support programs, coinciding with our result stating that for high expenditure values, cost support policy achieves higher social welfare than the price support
policy that announces the minimum guaranteed price. Wallace (1962) analyzes the social cost of production quotas and price subsidy policy under perfect competition and show that the social cost of implementing production quotas is greater than the cost of price subsidy if the absolute value of the demand elasticity is greater than the supply elasticity. This stream of literature does not examine the farmers’ decision making process and how it is impacted by the implementation of the policy instruments. We complement this literature by providing a general theoretical framework for the study of agricultural policies by modeling the farmers’ optimization problem under competition and analyzing the impact of interventions on farmers’ decisions as well as the welfare of the consumers and the government.

Within the operations management literature, several papers study questions related to production planning and capacity management in the context of agribusiness. Some of these papers investigate a processor’s production planning problem given that the firm procures agricultural inputs and faces quality uncertainty that is dependent on the random yield (Boyabatli and Wee 2013), a processor’s input processing and output storage capacity optimization problem under yield and spot price uncertainty (Boyabatli et al. 2014), a meat processor’s procurement, processing and production decisions under different contracting options (Boyabatli et al. 2011), a producer’s production planning problem under random yield when the firm can lease farm space at the beginning of the growing season (Kazaz 2004, Kazaz and Webster 2011), the optimization of procurement and processing decisions of a soybean processing company (Devalkar et al. 2011), the problem of choosing a contract that ensures supply risk sharing among the supply chain stakeholders (Kouvelis and Xiao 2015), the price and quantity decisions of a monopolistic agrivendor operating under random yield and the problem of an upstream supplier (farmer) selling to a downstream agrivendor through a wholesale price contract (Kouvelis et al. 2015). Furthermore, Federgruen et al. (2015) explore a setting in which a manufacturer interacts with multiple farmers and study the manufacturer’s problem of choosing which farmers to contract with and how to distribute the supply to the production facilities. Kouvelis and Li (2015) study a cotton supply chain consisting of a ginner and a farmer and explore contract types in order to achieve yield risk sharing among the two parties. Huh and Lall (2013) investigate a farmer’s irrigation capacity and land allocation problem and Boyabatli et al. (2016) study a farmer’s land allocation problem in the presence of two crops with rotation benefits. Our work contributes to this branch of literature by studying the impact of competition among farmers, which is prevalent in most of the agricultural settings, on farmers’ decisions and the rest of the agricultural supply chain.

The stream of literature that is most relevant to our work studies various policy instruments in different settings. Some of these papers investigate the role of subsidies in promoting green technology (Acemoglu et al. 2012), increasing the availability of malaria drugs (Taylor and Xiao
2014), and ensuring efficient distribution of surface water among farms with different proximity to water sources (Dawande et al. 2013). Zago and Pick (2004) investigate the welfare impacts of labeling regulation on agricultural commodities. Levi et al. (2013) study the allocation of subsidies to increase the consumption of a good that has positive externalities on the society. Kazaz et al. (2016) study the availability problem of the artemisinin-based malaria medicine and explore the directional effects of various supply chain interventions including price support and yield enhancement on the amount of farm space dedicated to artemisinin production and expected artemisinin volume. Expanding this work, we study the impact of policy instruments on the stakeholders along the supply chain as well as the return on government spending. Moreover, our work analyzes how the equilibrium outcome responds to different implementation methods for price and cost support policies. Different from the findings of Kazaz et al. (2016) stating that increasing the expected yield results in an increase in supplier surplus, we characterize a parametric region in which the yield enhancing efforts hurt farmers’ expected profits due to the interplay of a number of market and crop characteristics.

Chen and Tang (2015) investigate the role of private and public market information on farmers’ profits in the presence of a Cournot competition when the public signal is provided by the government, which is commonly practiced in India. This paper does not consider the randomness in the production yield. Tang et al. (2015) focus on two types of information provision by the government, agricultural advice and market forecast information, using a setting in which farmers engage in Cournot competition under random production yield and study the impact of interventions on farmers. We complement this work by modeling the whole supply chain and exploring the effectiveness of agricultural policies in terms of the impact on the farmers, the consumers, and the government. Alizamir et al. (2015) study two types of farm subsidies practiced widely in the U.S., Price Loss Coverage (PLC) and Agriculture Risk Coverage (ARC). The former is exercised when the market price falls below a threshold set by the government whereas the latter takes effect when a farmer’s revenue is below a guaranteed level. The authors find that PLC induces an increase in planted acres whereas ARC may result in a reduction. Moreover, the government incurs lower cost under PLC when maximizing social welfare. Our paper differs from this work in that we investigate the role of implementation methods in addition to the policy instruments in achieving the maximum benefit to the stakeholders along the agricultural supply chain. Moreover, our analysis on the return on government spending helps us determine the conditions under which interventions are creating value.

3. Model
There are \( n \) farmers cultivating a crop under exogenous, random yield \( \phi \) that has a general distribution with mean \( \mu \) and standard deviation \( \sigma \) over support \( [\underline{\phi}, \bar{\phi}] \). Let \( f \) denote the PDF of \( \phi \). We
define $\kappa$ to be the second moment of the yield distribution, i.e. $\kappa = \mathbb{E}[\phi^2] = \mu^2 + \sigma^2$. We assume that farmers are subject to the same yield distribution\(^1\). This assumption is suitable for environments where weather is the main determinant of the production yield and farmers lie in close proximity to each other so that they are exposed to similar weather characteristics. Consumers are infinitesimally small with heterogeneous valuations uniformly distributed over the interval $[0, a]$ where $a$ is a finite, positive real number, and the total mass of consumers is normalized to 1. The timeline of events is as follows. In period 0, the government discloses some information about the intervention to be implemented. In the case of price and cost support policies, either the budget allocated to the intervention is made publicly available or the support price/unit subsidy (depending on the policy choice) is announced. Under the yield enhancement intervention, the policy maker discloses the expected yield improvement to be obtained through the intervention. Then, in period 1, farmers decide how much land to allocate to production. In period 2, the yield is realized, which determines the total supply, and the market clears.

Anticipating the future market price, each farmer decides how much land to allocate to production under a specific type of intervention. Let $x_j$ and $x_{-j}$ denote the amount of land allocated to cultivation by farmer $j$ and farmers other than $j$, respectively. The total amount of cultivated land, denoted by $x$, is then equal to $\sum_{j=1}^{n} x_j$, with the total supply being $\phi x$. We assume that by using $x_j$ acres of land, farmer $j$ incurs the production cost $c_1 x_j + c_2 x_j^2$. The linear component of the cost represents the expenditure on inputs such as seeds, fertilizers, power, irrigation. To avoid trivial solutions, we assume that $a \mu > c_1$. The quadratic component in the cost function mimics the capacity constraints. Unlike large farms in developed countries that enjoy economies of scale due to mechanization benefits, in developing countries, farmers are usually very small and it is harder for them to operate on larger farm space since financial constraints limit their ability to introduce more efficient production techniques. Hence, the quadratic cost component precisely captures the diseconomies of scale prevalent in developing countries. Quadratic costs also allow us to incorporate risk aversion into the farmers’ problem. Small farmers are usually considered to be risk averse, but introducing a concave utility function complicates the analysis considerably. Hence, we use quadratic costs to capture that effect.

In this paper, we focus on the setting in which markets clear locally as is often the case in remote areas in developing countries. In those regions, transportation is costly, hence farmers and consumers transact through the regional market. Additionally, small farmers in developing economies do not have access to storage and thus, they often lack the flexibility to strategically adjust the supply pushed to the market depending on prices. Also, these farmers are usually in need

\(^1\)It is straightforward to extend our results to the case of IID yields.
of cash in order to maintain their operations and daily activities, causing them to prefer selling their entire harvest in the market, constituting the basis of our single-period model. Farmers engage in Cournot competition when choosing how much land to cultivate and act as price-takers. On the consumer side, the demand function is shaped by the market price and consumers’ willingness to pay. Once the yield (and hence, the supply) is realized, the price is determined by the market clearing condition. The market price is denoted by \( p \).

We denote the ex-ante total expected profit of farmers, the consumer surplus, and the social welfare as \( \Pi_F, \Pi_C, \) and \( \Pi_{SW} \), respectively. We define social welfare as the sum of the expected profit of farmers and the consumer surplus, i.e. \( \Pi_{SW} = \Pi_F + \Pi_C \). We use the superscript \( i \) to denote the intervention type or the no-intervention case. Let \( NI \) denote the case of no intervention and \( PS, CS, \tilde{PS}, \tilde{CS} \) refer to price and cost support when the total budget is announced, price support when the support price is announced, and cost support when the unit subsidy is announced, respectively. Lastly, \( YE \) denotes the yield enhancement intervention. The change in the expected profit of farmers upon the implementation of intervention \( i \) for \( i \in \{ PS, CS, \tilde{PS}, \tilde{CS}, YE \} \), is denoted by \( \Delta \Pi_F \) and calculated as \( \Delta \Pi_F = \Pi_F^i - \Pi_F^NI \). \( \Delta \Pi_C \) and \( \Delta \Pi_{SW} \) are defined similarly. Lastly, we define the net government surplus under intervention \( i \), denoted by \( \Delta \Pi'^i_G \), as \( \Delta \Pi'^i_G = \Delta \Pi'^i_{SW} - B \) where \( B \) is the government budget.

3.1. Benchmark case: No Intervention

We first analyze the benchmark case with no government intervention. In period 2, given the market price \( p \), a consumer buys the commodity if her valuation is greater than or equal to \( p \). This determines the total demand in the market, which is given by \( Q_{Demand} = \frac{(a - p)}{a} \). Since the yield has been realized by that point in time, the total supply, \( \phi X \), is also known, resulting in the market clearing price, \( p = a (1 - \phi X) \). Note that the linear demand function is widely used in the literature for tractability purposes (Mendelson and Tunca 2007, Popescu and Seshadri 2013).

In period 1, anticipating the future spot prices, farmers make allocation decisions. For fixed \( x_i \), farmer \( j \) solves the optimization problem

\[
\max_{x_j \geq 0} \mathbb{E} [p \phi x_j] - (c_1 x_j + c_2 x_j^2)
\]

where \( p = a (1 - \phi (x_j + x_{-j})) \). The objective function is concave, resulting in a unique maximizer given by \( x_j^{NI} = \frac{a \mu - c_1 - a \kappa x_j^{NI}}{2(a \kappa + c_2)} \). Since farmers are homogeneous, we will focus on the symmetric equilibrium.

**Proposition 1.** Total amount of land allocated to production in equilibrium under the benchmark case is given by \( x^{NI} = \frac{n(a \mu - c_1)}{a(n + 1)n + 2c_2} \). This quantity is decreasing in \( c_1, c_2, \sigma \) and increasing in \( a, n \).
As production gets costlier, resulting in a reduction in profitability, the amount of land allocated to cultivation decreases. The opposite happens as consumers are willing to pay higher prices. Competition on the other hand, has a negative impact on an individual farmer’s profitability. Even though each farmer’s land allocation decreases with increasing competition, total land allocation increases. As a result, due to the higher supply, consumers benefit from increasing competition.

An important point is that even though farmers are expected profit maximizers, we see that the equilibrium land allocation depends on yield variability. In fact, $x^{NI}$ is decreasing in $\sigma$. The reason that yield variability plays a role in this problem is that not only the supply but also the market price is affected by the yield. A crop with high yield variability causes high volatility in both the price and the supply, resulting in farmers’ being more cautious about the amount of land dedicated to cultivation\(^2\)

The functional form of farmers’ expected profits depends on the intervention type and the implementation process and will be calculated in the following sections. On the other hand, consumer surplus is affected by the intervention type only through land allocation and calculated as given below for $i \in \{NI, PS, CS, PS, CS, YE\}$.

$$\Pi_i^C = \mathbb{E}[\phi \int_p^a (v - p) \, dv] = \mathbb{E}[\phi \int_a^{\infty} \left( v - a \left( 1 - \phi x^i \right) \right) \, dv] = \frac{a \kappa (x^i)^2}{2}. \quad (1)$$

4. Interventions

In this section, we investigate price support and cost support interventions under two implementation methods: the government announces (1) the total budget or (2) the unit support (support price or unit subsidy), at the beginning of the planting season, prior to farmers’ land allocation decisions. We also investigate the yield enhancement intervention whose implementation entails the government’s disclosure of the expected yield improvement.

4.1. Price Support

4.1.1. Implementation Method I: Budget is announced

Let $p^G$ denote the support price that corresponds to the announced budget in equilibrium. That is, given the budget, the support price is determined depending on the total land allocation in equilibrium. If $p < p^G$, the government makes a deficiency payment to farmers, otherwise, no intervention occurs. Under this policy, the total expected payment to farmers is given by $\mathbb{E}[(p^G - p) \phi x 1\{p^G > p\}]$, which is equal to the budget set by the government, $B$. As in the case of

\(^2\)In the case of IID yields, the impact of yield variance on land allocation is less prominent since only the own yield variance affects the expected profit of a farmer. In reality, farmers’ yields may not be independent or perfectly correlated. In that case, we expect the yield variance to play a larger role in the equilibrium land allocation as the correlation between the yields increases.
no intervention, the market price ensures market clearing in period 2. In period 1, farmer $j$ solves the problem
\[
\max_{x_j} \mathbb{E} \left[ p \phi x_j + (p^G - p) \phi x_j 1\{p^G > p\} \right] - (c_1 x_j + c_2 x_j^2) \tag{2}
\]
where $p = a (1 - \phi (x_j + x_{-j}))$. Since $p^G$ is dependent on the equilibrium allocation and the budget, we can rewrite the problem as
\[
\max_{x_j} \mathbb{E} [p \phi x_j] + \frac{B x_j}{x_j + x_{-j}} - (c_1 x_j + c_2 x_j^2) \tag{3}
\]
where the second term is due to $\mathbb{E} [(p^G - p) \phi x 1\{p^G > p\}] = B$. The total amount of land allocated to production under the symmetric equilibrium is then given by
\[
x^P = n \left( a \mu - c_1 \right) + \sqrt{n^2 (a \mu - c_1)^2 + 4B (n - 1) (a (n + 1) \kappa + 2c_2)} \over 2 (a (n + 1) \kappa + 2c_2). \tag{4}
\]

**Proposition 2.** Compared to the no-intervention case, total amount of land allocated to production, farmers’ expected profits, consumer surplus, and social welfare increase under price support when the total budget is public information.

By protecting farmers against the downside risk, price support intervention incentivizes overproduction, resulting in farmers’ obtaining less profit from the market compared to the benchmark case. Nevertheless, the payment from the government recovers farmers’ losses so that they are better-off under the intervention. The resulting increase in the supply and the reduction in the price due to the intervention benefit consumers in that a higher portion of the consumer population can now afford to buy the crop at a cheaper price. Overall, the social welfare increases under price support, however, it is not clear how the surplus created by the intervention is distributed between the stakeholders of the agricultural supply chain. To address this question, we define the impact ratio $\alpha^i = \Delta \Pi^i / \Pi_{NI}^i$ for $i \in \{PS, CS, \widetilde{PS}, \widetilde{CS}, YE\}$.

**Proposition 3.** Under price support, when the budget is announced by the government, the % increase in farmers’ profits is greater than the % increase in consumer surplus, i.e. $\alpha^{PS} > 1$, and $\alpha^{PS}$ is increasing in $c_1$, $\sigma$, and $B$, and decreasing in $n$.

Even though the price support policy induces overproduction, if the government discloses information about the total budget, the distortion, and hence the surge in supply, created by the intervention is not high enough to assure a higher percentage increase in the consumer surplus. As production gets costlier, the profit margins shrink, resulting in a greater need for government support from the farmers’ perspective. Similarly, high yield variance generates high uncertainty in profits, enhancing the benefit from the price guarantee provided by the government. Conversely, as competition among producers increases, the discrepancy in the surplus allocation shrinks. In the
case of crops that are produced by a vast portion of the producer population, such as rice in the Philippines and Indonesia, price support intervention creates less discrepancy in terms of the beneficial impact on the farmers and the consumers compared to less mainstream crops or compared to the case in which farmers form cooperatives rather than engage in competition. That is, more competitive environments induce greater distortion in the market, thus benefiting consumers more due to the higher availability of the crop. Lastly, even though allocating a higher budget on the intervention benefits both parties, the impact on farmers’ expected profits is higher.

Even though a policy instrument may achieve an increase social welfare, an important consideration is whether an additional value is generated through the use of the policy in excess of the government spending. Ideally, policy makers would want to create an impact on social welfare that is at least as big as the expenditure when using an intervention. If that is not the case, the government incurs a negative return on the intervention even though social welfare is improved. The following proposition addresses this issue for the price support intervention.

**Proposition 4.** Government surplus under price support when the budget is announced, $\Delta \Pi_{PG}^{PS}$, is concave in $B$ and there exists a threshold

$$\tilde{B}_{PS}^{PS} = \frac{2an^2\kappa (a\mu - c_1)^2 (a(n+2)\kappa + 2c_2)}{(n-1)(an\kappa + 2c_2)^2 (a(n+1)\kappa + 2c_2)}$$

such that the government incurs a positive return if $B \leq \tilde{B}_{PS}^{PS}$, and negative return otherwise.

**Corollary 1.** $\Delta \Pi_{PG}^{PS}$ and $\tilde{B}_{PS}^{PS}$ are increasing in $a$, $\mu$ and decreasing in $c_1$, $c_2$. Moreover if $c_2 = 0$, $\tilde{B}_{PS}^{PS}$ is decreasing in $n$ and $\sigma$, and $\Delta \Pi_{PG}^{PS}$ is decreasing in $n$ for $n \geq 3$ and $\sigma$.

**Figure 1** Impact of price support on farmers’ expected profits, consumer surplus, social welfare and government surplus (when the budget is announced)

Note. $a = 10, \mu = 100, \sigma = 10, c_1 = 10, c_2 = 5, n = 10$. 
Under price support, the incremental impact on social welfare is diminishing as more money is allocated to the intervention, causing a net loss from the government’s perspective after a certain budgetary threshold. As a result of overproduction induced by the intervention, farmers experience profit losses in the market whereas consumers benefit from the supply increase and price reduction. If the intervention cannot generate a gain to consumers that is greater than the farmers’ losses, the government incurs a negative return. In this case, the distortion created by the anticipation of government support negatively impacts social welfare and the payment from the government is needed to make up for this loss.

As can be seen in Figure 1b, price support generates a positive surplus for the policy maker for a larger set of expenditure values as $\tilde{B}_{PS}$ increases. Small profit margins in the case of low value crops or crops with high production costs/low yields exacerbate farmers’ losses in the market due to overproduction, shrinking the set of expenditure values that generate positive return for the government. In the absence of quadratic costs, i.e. when there is no diseconomies of scale, farmers are more inclined to engage in overproduction, thus, incurring larger losses under increasing competition or yield variability (due to higher probability of instances with high yield). Overall, the policy maker obtains greater surplus using the price support policy with the announcement of the budget for high value, high expected yield, low cost crops.

4.1.2. Implementation Method II: Support price is announced

In this section, we explore the case in which the government announces the support price rather than the budget prior to farmers’ allocation decisions. Let $\tilde{p}^G$ denote the support price which is usually set by adding a margin on top of the cost of production so that farmers are guaranteed a minimum level of income. The optimization problem solved by farmer $j$ remains the same as the one presented in (2), but in this case the expenditure incurred by the government depends on the equilibrium allocation. The first order condition to (2) in a symmetric equilibrium is given by

$$a\mu - c_1 - (a(n + 1)\kappa + 2c_2)x_j^{\tilde{PS}} + \int_{a-\tilde{p}^G}^{\tilde{\phi}} \left( \tilde{p}^G - a \left( 1 - \phi(n + 1)x_j^{\tilde{PS}} \right) \right) \phi f(\phi) d\phi = 0 \quad (5)$$

which can be rewritten as

$$a\mu - c_1 - (a(n + 1)\kappa + 2c_2)x_j^{\tilde{PS}} + \frac{B}{nx_j^{PS}} + ax_j^{\tilde{PS}} \int_{a-\tilde{p}^G}^{\tilde{\phi}} \phi^2 f(\phi) d\phi = 0. \quad (6)$$

where $B$ is the resulting expected government expenditure. Also, the second order condition is given by

$$-2a \int_{\phi}^{a-\tilde{p}^G} \phi^2 f(\phi) d\phi - 2c_2 + \frac{(a-\tilde{p}^G)^3}{a^2n^4}x_j^{PS} f \left( \frac{a-\tilde{p}^G}{anx_j^{PS}} \right) < 0. \quad (7)$$
Note that for large enough quadratic costs, the second order condition is satisfied. However, a closed form solution to this problem cannot be obtained without further assumptions on the yield distribution. Nevertheless, we can make a comparison between the two implementation processes regarding the price support intervention as shown in the next proposition.

**Proposition 5.** Assuming that the condition given in (7) holds and keeping the expected expenditure fixed, under price support, the total amount of land allocated to production is larger if the government announces the support price compared to the case where the total budget is announced.

**Proposition 6.** Under price support, if the government announces the support price, $\alpha \hat{P} S < 1$.

Compared to providing farmers with information about the budget allocated to the price support program, disclosing the guaranteed support price generates greater incentives for farmers to overproduce, resulting in greater market distortion. In the latter, each farmer is motivated to produce more to gain more profits as the worst-case price is pre-announced by the government whereas in the former case, the amount of support each farmer receives from the government is the result of the total production, undermining the perceived benefits from the intervention. Since production is higher under the announcement of the support price, consumers are better-off whereas farmers are worse-off compared to the case of budget announcement keeping the expected government expenditure the same. This differentiation between the two implementation methods helps correct for the welfare inequity between the farmers and the consumers. In implementing price support, the policy maker should provide information about the budget if the goal is to support farmers’ incomes without introducing much distortion in the market. This could be the case if the yields are high or there is substantial competition in the market, resulting in high availability of the crop for the consumers, thus eliminating the need to support the consumer side of the market and placing the priority on supporting farmers’ incomes as they struggle with low market prices. Conversely, if the policy maker’s goal is to increase the availability of affordable food to consumers, then announcing a price floor that mitigates the risk farmers are exposed to would serve that goal by incentivizing them to inflate production, thus improving consumer surplus more than farmers’ profits.

4.2. Cost Support

4.2.1. Implementation Method I: Budget is announced

Let $\Delta c_1$ denote the input subsidy per acre of land corresponding to the budget set by the government in equilibrium. That is, similar to the case in price support, $\Delta c_1$ is determined depending on the equilibrium outcome and the pre-announced budget. Under this subsidy scheme, farmer $j$'s
cost of production on \( x_j \) acres of land becomes \((c_1 - \Delta c_1)x_j + c_2x_j^2\) and the total subsidy payout to farmers is \(\Delta c_1 x\). Farmer \( j \)'s optimization problem is given as

\[
\max_{x_j \geq 0} E[p\phi x_j] - \left((c_1 - \Delta c_1) x_j + c_2x_j^2\right) \tag{8}
\]

which can be rewritten as

\[
\max_{x_j \geq 0} E[p\phi x_j] + \frac{Bx_j}{x_j + x_{-j}} - \left(c_1x_j + c_2x_j^2\right) \tag{9}
\]

since \(\Delta c_1 (x_j + x_{-j}) = B\). Note that this is the same optimization problem as in the case of price support, which brings us to the following proposition.

Proposition 7. If the budget is public information, land allocation, farmers’ expected profits, consumer surplus, and social welfare are the same under price and cost support interventions using the same expected government expenditure.

By announcing the budget allocated to the intervention, the policy maker establishes the total (expected in the case of price support) amount of monetary support to be provided to the farmers. Under cost support, the monetary support from the government is provided in the form of input subsidies, reducing farmers’ costs and thus increasing profits. Under price support, farmers receive deficiency payments from the government in low market price realizations, resulting in an increase in expected profits. In this case, the expected monetary support from the government is equal to the total budget allocated to the intervention. Overall, both policy instruments impact farmers’ decision making by increasing the profitability of production, and hence, under the same expected government expenditure, both interventions generate the same impact and induce the same equilibrium land allocation. This result shows that price and cost support policies are effectively the same in expectation if the government chooses to announce the budget prior to the planting season. However, this finding does not hold if the support price or the unit subsidy is announced as shown in the next section.

4.2.2. Implementation Method II: Unit subsidy is announced

In this section we investigate the case in which the government announces the unit subsidy per acre, denoted by \(\tilde{\Delta}c_1\), instead of the budget allocated to the cost support intervention. In this case, the solution to farmer \( j \)'s optimization problem given in (8) becomes

\[
x_{j}^{CS} = \frac{a\mu - c_1 + \tilde{\Delta}c_1}{a(n+1)\kappa + 2c_2} \tag{10}
\]

where \(\tilde{\Delta}c_1nx_{j}^{CS} = B\) since the government expenditure is contingent on the equilibrium. Thus, we can rewrite \(x^{CS}\) as a function of \(B\) as follows.

\[
x^{CS} = \frac{n(a\mu - c_1) + \sqrt{n^2(a\mu - c_1)^2 + 4Bn(a(n+1)\kappa + 2c_2)}}{2(a(n+1)\kappa + 2c_2)} \tag{11}
\]
Proposition 8. Under cost support, keeping the government expenditure the same, the amount of land allocated to production is greater if the unit subsidy is disclosed compared to the case of budget announcement. Moreover, assuming that the condition given in (7) holds, under the same expected government expenditure, price support yields higher land allocation when the support price is announced compared to cost support when the unit subsidy is announced.

If the subsidy per acre is announced by the government prior to the planting season, since the total support a farmer receives is contingent on the amount of land cultivated, farmers are incentivized to increase their acreage compared to the disclosure of the total budget. Furthermore, unlike the case where the budget is public information, price and cost support interventions are not equivalent. When farmers are only informed about the total budget that is expected to be spent on agricultural interventions, their expectations about how much monetary support each farmer will receive are the same under both price and cost support. On the other hand, when the unit subsidy is disclosed under cost support, each farmer knows the exact amount of monetary support to be received from the government whereas when the support price is announced under price support policy, the probability of receiving a deficiency payment depends on other producers’ actions as well. That is, the monetary payout to a farmer is based only on the farmer’s own land allocation decision under cost support whereas it depends on the total production as well as the random yield under price support. This underlying distinction results in the difference in equilibrium allocations of the two policies. In fact, since there should be excess supply in the market in order for the price support policy to be exercised, farmers produce more compared to the cost support policy.

Given that disclosing the unit subsidy under cost support results in less market distortion compared to price support with the announcement of the support price, and more market distortion compared to both price and cost support in the case of the disclosure of the budget, we investigate whether such a moderate-distortion policy achieves equity in the farmers’ and consumers’ welfare improvement.

Proposition 9. Under cost support, if the government announces the unit subsidy, total amount of land allocated to production, farmers’ expected profits, consumer surplus, and social welfare increase compared to the no-intervention case. Moreover, in this case, $\alpha CS = 1$.

As stated in Proposition 9, the cost support policy attains the same percentage increase in farmers’ profits and consumer surplus if the government discloses the subsidy per acre to be paid out to farmers. In this case, the intervention cannot help correct for the pre-existing welfare inequity between the farmers and the consumers, but rather ensures that both parties benefit from the intervention in equal proportion. Overall, our results so far indicate that low-distortion interventions, such as price and cost support with the announcement of the budget, favor farmers more whereas
high-distortion interventions, such as price support with the disclosure of the minimum guaranteed price, benefit consumers more. On the other hand, moderate-distortion interventions such as cost support with the unit subsidy announcement can achieve equity in the impact achieved on both parties.

**Proposition 10.** Government surplus under cost support when the unit subsidy is announced, \( \Delta \Pi_G^{\text{CS}} \), is concave in \( B \) and there exists a threshold

\[
\tilde{B}_{\text{CS}} = \frac{2an\kappa (a\mu - c_1)^2 (a(n+2)\kappa + 2c_2)}{(an\kappa + 2c_2)^2 (a(n+1)\kappa + 2c_2)} < \tilde{B}^{\text{CS}} = \tilde{B}^{\text{PS}}
\]

such that the government incurs a positive return if \( B \leq \tilde{B}_{\text{CS}} \), and negative return otherwise.

Similar to the case under price and cost support policies with the disclosure of the budget as shown in Proposition 4, if the unit subsidy is announced under cost support, the government generates positive return on the intervention up to a certain budgetary threshold, after which point the losses due to the market distortion exceeds the benefits of the intervention (not including the subsidy payments from the government), resulting in a negative return. Since announcing the unit subsidy to be paid out to the farmers creates more distortion compared to the announcement of the total budget, the return on intervention becomes negative for lower budget values. That is, given a high enough budget allocated to the agricultural policy, the disclosure of the unit subsidy results in a negative return whereas it is possible to generate a positive return through low-distortion interventions.

**4.3. Comparison of Price and Cost Support**

In this section, we broaden the comparison of price and cost support policies under the two policy implementation methods discussed thus far by studying the impact on farmers’ expected profits, consumer surplus, and social welfare while keeping the expected government expenditure fixed. The results are summarized in Table 1.

**Proposition 11.** Under the same expected government expenditure,

(i) Farmers’ expected profits are

(a) lower under price support when the support price is announced compared to cost support when the unit subsidy is announced,

(b) the highest when the government announces the total budget.

(ii) Consumer surplus is

(a) lower under price/cost support when the total budget is announced compared to cost support when the unit subsidy is announced,

(b) the highest under price support when the support price is announced.
Proposition 11 states that high-distortion interventions are desirable from the consumers’ perspective due to the higher availability of the agricultural commodities whereas low-distortion interventions ensure higher incomes for farmers. Note that if overproduction due to the incentives provided by the intervention is attained by farmers’ abandoning other crops to increase the amount of land allocated to the subsidized crop, consumers may suffer from the scarcity of the abandoned crop in the absence of substitutability. In that case, high-distortion interventions may not be beneficial for the consumers. This could be true for crop-specific interventions such as price support and subsidies on seeds whereas generic interventions such as fertilizer subsidies do not cause conversion to monoculture. In fact, this point supports the criticisms on price support regarding its role in promoting monoculture, thus causing environmental degradation as well as lower availability of other commodities. However, in Indonesia and the Philippines, since rice is the staple food, the governments aim to achieve self-sufficiency in rice production and affordable access to rice by consumers. As a result, an increase in production motivated by the price support policy serves the policy maker’s goal of self-sufficiency as well as benefit the consumers due to higher availability of the staple food. Also, the majority of the farmer population is already engaged in rice production in these countries, in fact 85% and 59% of arable land is dedicated to rice cultivation in the Philippines and Indonesia, respectively, making abandonment of other crops less of a concern.

<table>
<thead>
<tr>
<th>Implementation Process</th>
<th>What is public information?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Budget</td>
</tr>
<tr>
<td>Total land allocation</td>
<td>$x^{CS} = x^{PS}$</td>
</tr>
<tr>
<td>Farmers’ expected profits</td>
<td>$\Pi^{PS}_F &gt; \Pi^{PS}_C &gt; \Pi^{PS}_F$</td>
</tr>
<tr>
<td>Consumer surplus</td>
<td>$\Pi^{CS}_C &lt; \Pi^{CS}_C$</td>
</tr>
<tr>
<td>Impact ratio</td>
<td>$\alpha^{CS} &gt; 1$</td>
</tr>
</tbody>
</table>

Table 1  Comparison of intervention implementation processes

Proposition 12. Under the same expected government expenditure,

(i) If $B < \frac{\alpha n \kappa (\alpha - c_1)^2}{(\alpha n + \delta c_2)^2}$, social welfare is higher under cost support when the unit subsidy is announced compared to price/cost support when the total budget is announced,
(ii) If $B > \frac{a_n^2(\alpha_n - c_1)^2}{(n-1)(a_n + 2c_2)^2}$, social welfare is highest when the government announces the total budget and lowest under price support when the support price is announced.

As shown in Table 1, under low-budget agricultural policy, interventions that cause higher distortion in the market, such as cost support with the disclosure of the unit subsidy, do not cause much disturbance due to the budgetary constraints on the incentives provided to the farmers, thus resulting in higher social welfare. In this case, disclosure of the support price may result in higher or lower social welfare compared to the case of unit subsidy announcement. On the other hand, the distortion caused by the announcement of the unit support, whether it is the support price or the unit subsidy, is detrimental to farmers’ profits if the government expenditure is high, causing a lower social welfare compared to the disclosure of the budget.

Overall, the policy maker should choose the policy instrument and the implementation method depending on the budget and whether farmers or consumers are prioritized. Announcing the support price, which is commonly used in many countries in implementing the price support policy, is the most aggressive among the policy implementation methods studied so far. This finding supports the criticisms regarding the shift towards monoculture caused by the incentives provided by the price support programs. It is important to note that the policy maker can diminish the distortion created by the intervention by signaling the amount of budget allocated to the intervention instead of specifying the support price guaranteed to farmers. Moreover, cost support policies in the form of input subsidies are less aggressive in terms of the market distortion caused by the intervention. Additionally, if the subsidy is provided for a generic input such as fertilizers, pesticides, power etc., eliminating the incentives to engage in monoculture, the downside of crop-specific price support intervention is avoided.

We use our findings to inform policy choice in Indonesia and the Philippines in rice production. Indonesia uses fertilizer subsidies extensively in order to increase agricultural profitability and encourage farmers to cultivate rice along with a nominal price support program implemented for palay farmers. On the other hand, the Philippine government places more emphasis on supporting producer prices, thus allocating considerable funds to the price support policy implemented by NFA by announcing the guaranteed minimum prices for palay farmers. According to our results, Indonesia’s investment in fertilizer subsidies is less effective in terms of boosting rice production compared to the price support policy considering the goal of achieving self-sufficiency in rice common to both countries. However, given the same expected government expenditure, Indonesia can attain higher benefit to farmers using fertilizer subsidies, and also achieve higher social welfare if the expected expenditure is high enough. Our findings are aligned with the empirical findings of Barker and Hayami (1976) obtained by analyzing price support and input subsidy policies using data from the Philippine rice economy.
4.4. Yield Enhancement

Different from other types of interventions studies thus far, in this section we explore the impact of yield enhancing efforts undertaken by the government in order to improve productivity. Unlike price and cost support, yield enhancement efforts do not entail a payment from the government to the farmers, but rather involves the government’s investment in research and development in order to increase seed varieties, seed resistance to pests or educating farmers on efficient farming practices and mechanization.

In the case of yield enhancement efforts, it is common for the government to announce the expected yield improvement to be obtained as a result of the intervention. Let \( \delta > 1 \) denote the multiplicative factor on the expected yield upon the implementation of the intervention. We assume \( \delta \) is a non-decreasing, bounded function of \( B \) but we do not need to define a functional form to derive our results in this section. Let \( \tilde{\phi} \) denote the yield resulting from the intervention with mean \( \tilde{\mu} \) and standard deviation \( \tilde{\sigma} \). We formulate \( \tilde{\phi} \) as

\[
\tilde{\phi} = \phi + (\delta - 1) \mu
\]

which gives \( \tilde{\mu} = \delta \mu \) and \( \tilde{\sigma} = \sigma \). We assume that the yield enhancing efforts increase the expected yield but has no impact on yield variability. Even though having access to resources such as pest resistant seeds or more efficient production techniques might reduce yield variability, a major determinant in that regard is weather. As yield enhancement techniques do not reduce the variability due to weather conditions, we assume that \( \sigma \) remains unaffected. We define \( \tilde{\kappa} = \delta^2 \mu^2 + \sigma^2 \). In this case, farmer \( j \)'s optimization problem becomes

\[
\max_{x_j \geq 0} E \left[ p \tilde{\phi} x_j \right] - (c_1 x_j + c_2 x_j^2)
\]

where \( p = a \left( 1 - \tilde{\phi} (x_j + x_{-j}) \right) \). Note that this is the same optimization problem as in the case of no intervention except for the shift in the yield distribution. Hence, the total amount of land allocated to production in equilibrium is given as

\[
x^{YE} = \frac{n(a\delta \mu - c_1)}{a(n+1)\tilde{\kappa} + 2c_2}.
\]

The following proposition summarizes the impact of yield enhancing efforts on the supply chain.

**Proposition 13.** Compared to the no-intervention case, the total amount of land allocated to production increases if and only if \( \delta < \left( \frac{(n+1)\mu}{(n+1)\mu + c_1} + 2c_2 \right) \) under the yield enhancement intervention whereas the expected total supply increases \( \forall \delta > 1 \). Consumer surplus and social welfare increase while farmers’ expected profits

(i) increase if \( c_2 = 0 \),
(ii) decrease if \( a, c_2, \) and \( n \) are greater than \( \delta \)-dependent thresholds and the coefficient of variation of the yield is less than \( \sqrt{\delta} \).

As Proposition 13 states, yield enhancing efforts could result in a decline in the amount of cultivated land. For high values of yield improvement, farmers are no longer incentivized to increase cultivation as they experience increased productivity. As a matter of fact, if they increase the amount of land allocated to production, they are likely to incur losses during the selling season as the surge in supply will suppress prices. On the other hand, expected supply always increases. As opposed to monetary interventions such as price and cost support, under yield enhancement, the increase in supply does not solely result from the increase in acreage, in fact, if the expected yield improvement is high, supply increases despite the reduction in acreage. As a result, the benefit to consumers mostly results from the increased productivity.

We find that yield improvement does not always increase farmers’ profits, which seems counter-intuitive as productivity improvement is often desirable in agriculture. However, under some parametric conditions, market and producer characteristics undermine the benefits from an expected increase in yield, resulting in a reduction in farmers’ profits. First, when the number of farmers is high, it is harder to generate a positive impact on the supplier side of the market through an increase in yield as high competition causes the supply on the market to be abundant to begin with. As a result, even though the increased yields benefit an individual farmer due to the increased volume of the harvest, if all the other farmers also experience such a yield improvement, that would suppress the prices. Similarly, as each farmer gets smaller, causing them to be more risk averse and prone to diseconomies of scale, the price risk that comes with a surge in supply is more emphasized and the yield enhancement intervention is less effective. Lastly, if the value of the crop is high, the decline in the expected market price due to the surge in supply is higher, constituting a challenge in creating a positive impact on farmers through yield enhancement. However, even under these conditions, farmers benefit from an improvement in yield if the yield distribution has high dispersion as in this case, yield enhancing efforts help mitigate the low yield instances. On the other hand, if the yield distribution has low dispersion on top of the conditions described above, farmers do not need protection against the downside risk of the yield as such a risk does not play an important role in farmers’ profits, resulting in a reduction in profits due to the intervention. Conversely, in the absence of quadratic costs, i.e. diseconomies of scale, farmers attain an increase in profits under yield enhancement. So overall, depending on the interplay of the features that shape farmers’ decision process including competition, risk aversion, value of the crop and the dispersion in the yield distribution, yield enhancement may not be advantageous for farmers. Hence, not considering particular characteristics that could be inherent to small producers could
cause one to overlook important market factors and mislead the policy maker when choosing the appropriate policy. Finally, our results indicate that the yield enhancing efforts always result in an improvement in social welfare, meaning that even if the farmers incur losses, the gain to the consumers is large enough so that intervention generates a positive overall impact.

Next, we examine the relative impact of the yield enhancement intervention on farmers and consumers. Under yield enhancement, different from the interventions studied before, farmers gain higher profits in the market compared to the no-intervention case outside of the aforementioned parametric region. However, from the perspective of farmers, there are two forces that counteract in the case of a yield increase. On the one hand, supply increases, which would positively affect producers’ profits, but on the other hand, market price decreases due to abundant supply, resulting in a negative impact on profits. The two counteracting forces diminish the effectiveness of the intervention from the producers’ perspective even if the overall effect is positive whereas for consumers these forces act together in that an increase in supply and a reduction in price ensure that more consumers can afford to buy the commodity at a cheaper price. As a result, yield enhancing efforts attain a higher percentage increase in consumer surplus than farmers’ profits as shown in the following proposition.

**Proposition 14.** Under the yield enhancement intervention, $\alpha^{YE} < 1$ and it is decreasing in $n$ and increasing in $c_1$. However, under the special case of $c_2 = 0$, $\alpha^{YE} = 1$.

As stated in Proposition 14, increasing competition exacerbates the gap between the farmers and the consumers in terms of the impact on welfare achieved by the intervention as higher competition increases the total supply, undermining the benefits of yield improvement. Conversely, as production becomes costlier due to an increase in the linear cost component, productivity improvement becomes more valuable to farmers, helping close the gap. Note that in the absence of quadratic costs, yield enhancement intervention achieves equity in the impact on farmers and consumers. This justifies that farmers’ risk aversion reduces the effectiveness of the intervention due to the market price risk.

Since yield enhancement intervention does not entail monetary payments to the farmers, it is harder to measure the government surplus compared to price and cost support policies. To deduce the return on government spending, one has to derive the relationship between the improvement in yield and the expenditure on efforts exerted to achieve the corresponding improvement, which depends on the type of the method used to increase the yield, whether it is investing in research and development to obtain high yielding seed varieties or educating farmers on the use of agricultural methods and machinery geared towards increasing productivity. In some cases, the amount of investment needed to achieve a target expected yield may be crop and country specific as well.
Therefore, instead of deriving the explicit expression, we will deduce the characteristics of the government surplus.

**Proposition 15.** The increase in social welfare under the yield enhancement intervention, \( \Delta \Pi_{\text{SW}}^{YE} \), is decreasing in \( \sigma \) if and only if \( c_1 \) is greater than some \( \delta \)-dependent threshold.

For crops with high per acre production cost, which results in tight margins, higher yield variability undermines the benefits from an increase in expected yield due to the price risk generated by the high yield realizations. When the margins are tight, farmers have less capability in absorbing the reduction in price due to the abundant supply, which is caused by the increase in yields and high variability. Note that since the government surplus, \( \Delta \Pi_{\text{G}}^{YE} \), is simply given by \( \Delta \Pi_{\text{SW}}^{YE} - B \), where \( B \) is a function of \( \delta \), we conclude that yield variability has a diminishing impact on the return on government spending if the per acre production cost is high. That is, for tight margin, high variability crops, the government may experience weaker benefits from the yield enhancing efforts.

In this paper, we have analyzed the cost support and yield enhancement interventions separately whereas in reality, subsidizing the cost of fertilizers or high-yielding seeds could provide improvement in the yield, merging these two interventions and increasing farmers’ profitability through both cost reduction and productivity improvement. We can use our findings from the previous sections to interpret this scenario. First, the region in which farmers incur losses due to the yield improvement would expand if such an improvement is accompanied by a reduction in costs as a result of the additional market distortion caused by input subsidies. Secondly, since both interventions increase the expected supply when applied separately, the conjoined policy would also have an increasing effect on the expected supply, benefiting the consumers. Moreover, keeping the expenditure fixed, the government may achieve a higher societal impact through the conjoined policy. In this case, it might be desirable to provide subsidies for inputs that would enhance farmers’ yields as in the case of the hybrid rice commercialization program implemented in the Philippines from 2001 to 2006, which entailed the distribution of hybrid rice seeds that ensure higher yields at a subsidized rate in order to increase rice productivity (David 2006).

5. Conclusion
The importance of the agriculture sector in developing countries gives rise to the implementation of numerous policy instruments with the goals of poverty alleviation and economic development. Specifically, by utilizing agricultural policies, the policy maker aims to support farmers’ incomes while maintaining food security for the consumers. In this paper, we investigate very commonly used price and cost support policies as well as yield enhancement efforts in terms of their effectiveness in benefiting farmers and consumers, and impact on the government. We investigate two
implementation methods applicable to price and cost support interventions, (1) the government announces the budget allocated to the intervention, (2) the support price or the unit subsidy is specified, as understanding the impact of different implementation methods on the distortions generated by the intervention enables the policy maker to better utilize the resources allocated to the intervention.

We rank price and cost support policies under the two implementation methods in terms of the total land allocation, farmers’ expected profits, consumer surplus, and social welfare. We find that the announcement of the total budget results in less market distortion compared to the announcement of the unit support under both price and cost support. In fact, the greatest distortion in farmers’ production decisions is created by the price support policy when the minimum guaranteed price is announced. Under the same government expenditure, higher market distortion benefits the consumers due to the increase in the supply and the reduction in the price whereas farmers are better-off under interventions that cause less overproduction. Depending on the expected government expenditure, the social welfare may increase or decrease as distortions increase. For high-expenditure interventions, market distortions are detrimental to farmers’ profits, resulting in lower social welfare compared to policies that cause less distortion. From our analysis, we conclude that the policy maker may achieve higher social welfare under the same agricultural policy by switching to an implementation method that provides farmers with fewer incentives to overproduce. In our setting, this can be accomplished by signaling information about the budget rather than specifying the unit support in the case of high-expenditure interventions. The opposite is true for low-expenditure interventions as the policy maker needs to guarantee a unit support to farmers in order to achieve the highest impact possible under a limited budget. Furthermore, we find that the policy maker cannot always obtain positive return on spending through these interventions. After a certain budgetary threshold, the intervention ceases to generate added value through the impact in the market equilibrium, causing the government to obtain a negative return on the policy.

Finally, we explore another type of policy that does not entail a payment to the farmers, namely the yield enhancement intervention which has the goal of increasing agricultural productivity. We show that even though consumers benefit from the increased productivity, farmers may be worse-off under some conditions due to the increased competition effects induced by the intervention. However, an improvement in yield always results in an increase in social welfare.

Future research is needed in order to understand the impact of policy choice on farmers’ allocation decisions in the presence of multiple crop options. Our model focuses on the case of a single crop, which is suitable for the case of rice production in the Philippines and Indonesia where the majority of the arable land (85% in the Philippines, 59% in Indonesia) is allocated to rice, but further research is required to examine the impact of production quantity distortions on consumers’ access
to other crops. Under crop-specific policies such as price support and subsidies for seeds, even though the increase in the supply of the subsidized crop benefits consumers, the supply of other crops may decline as farmers switch to the subsidized crop, requiring the need for further analysis.

Appendix

Proof of Proposition 1.

The total amount of land allocated to production under the symmetric equilibrium is given by \( x_{N|I} = n x_{j|N} \) where \( x_{j|N} = \frac{a_\mu - c_1 - a_\kappa x_{j|N}}{2(a_\kappa + c_2)} \). resulting in \( x_{N|I} = \frac{n(a_\mu - c_1)}{a(n+1)\kappa + 2c_2} \). This is clearly decreasing in \( c_1, c_2 \) and \( \sigma \). Furthermore,

\[
\frac{\partial x_{N|I}}{\partial n} = \frac{n ((n+1)\kappa c_1 + 2c_2\mu)}{(a(n+1)\kappa + 2c_2)^2} > 0
\]

and

\[
\frac{\partial x_{N|I}}{\partial a} = \frac{(a_\kappa + 2c_2)(a_\mu - c_1)}{(a(n+1)\kappa + 2c_2)^2} > 0,
\]

proving the desired result.

Proof of Proposition 2.

Total amount of land allocated to production increases since

\[
x_{PS} - x_{N|I} = \sqrt{n^2(a_\mu - c_1)^2 + 4B(n-1)(a(n+1)\kappa + 2c_2) - n(a_\mu - c_1)} - \frac{2}{2(a(n+1)\kappa + 2c_2)} > 0.
\]

Farmers’ expected profits under price support is calculated as

\[
\Pi_{FS} = \mathbb{E} \left[ p_0 x_{PS} + (p^G - p) \phi x_{PS} 1 \{p^G > p\} \right] - \left( c_1 x_{PS} + c_2 \frac{(x_{PS})^2}{n} \right)
\]

\[
= \mathbb{E} \left[ a \left(1 - \phi x_{PS}\right) \phi x_{PS} \right] + B - \left( c_1 x_{PS} + c_2 \frac{(x_{PS})^2}{n} \right)
\]

\[
= (a_\mu - c_1) x_{PS} - a_\kappa \left( x_{PS} \right)^2 - c_2 \frac{(x_{PS})^2}{n} + B. \tag{12}
\]

The consumer surplus is \( \Pi_{CS} = \frac{a_\kappa (x_{PS})^2}{2} \) as given in (1). Note that the expected profits of farmers under the price support policy and the no-intervention case are equal when \( B = 0 \). Same holds for the consumer surplus as well. Since,

\[
\frac{\partial \Pi_{FS}}{\partial B} = \frac{(a_\kappa + c_2)(n-1) n (a_\mu - c_1) + (2a_\kappa n + c_2 (n+1)) \sqrt{n^2(a_\mu - c_1)^2 + 4B(n-1)(a(n+1)\kappa + 2c_2)}}{n (a(n+1)\kappa + 2c_2) \sqrt{n^2(a_\mu - c_1)^2 + 4B(n-1)(a(n+1)\kappa + 2c_2)}} > 0
\]

and

\[
\frac{\partial \Pi_{CS}}{\partial B} = \frac{a (n-1) \kappa \left( n (a_\mu - c_1) + \sqrt{n^2(a_\mu - c_1)^2 + 4B(n-1)(a(n+1)\kappa + 2c_2)} \right)}{2 (a(n+1)\kappa + 2c_2) \sqrt{n^2(a_\mu - c_1)^2 + 4B(n-1)(a(n+1)\kappa + 2c_2)}} > 0,
\]

\( \Pi_{FS} > \Pi_{FS}^{N|I} \) and \( \Pi_{CS} > \Pi_{CS}^{N|I} \) for \( B > 0 \). The result for social welfare immediately follows.
Proof of Proposition 3.

Since
\[
\frac{\Delta \Pi_{PS}^{F}}{\Pi_{PS}^{F}} - \frac{\Delta \Pi_{PS}^{C}}{\Pi_{PS}^{C}} = \frac{B(a(n+1)\kappa + 2c_2)^2}{n^2(a\mu - c_1)^2(\alpha + c_2)} > 0,
\]
we have \(\alpha_{PS} = \frac{\Delta \Pi_{PS}^{F}/\Pi_{PS}^{F}}{\Delta \Pi_{PS}^{C}/\Pi_{PS}^{C}} > 1\).

Let \(\chi = \sqrt{n^2(a\mu - c_1)^2 + 4B(n-1)(a(n+1)\kappa + 2c_2)}\) for ease of notation. Partial derivatives are given as follows.

\[
\frac{\partial \alpha_{PS}}{\partial c_1} = \frac{8Bn(a(n+1)\kappa + 2c_2)^2}{(\alpha + c_2)\chi(3n(a\mu - c_1) + \chi)^2} > 0.
\]

\[
\frac{\partial \alpha_{PS}}{\partial \sigma} = 4aB\sigma (a(n+1)\kappa + 2c_2) \left(2B(n-1)(a(n+1)\kappa + 2c_2) \left(n(a\mu - c_1)(a(n+1)\kappa + (3n-1)c_2) + c_2(n-1)\chi\right) - n^2(a\mu - c_1)^2(a(n+1)\kappa + 2c_2)n \left(\chi(n(a\mu - c_1))\right)\right) / \left((\alpha + c_2)^2\chi \left(2B(n-1)(a(n+1)\kappa + 2c_2) + n(a\mu - c_1)(\chi(n(a\mu - c_1)))\right)^2\right)
\]

\[
> 4aB\sigma (a(n+1)\kappa + 2c_2)n(a\mu - c_1)(a(n+1)\kappa + 2c_2) \left(2B(n-1)(a(n+1)\kappa + 2c_2) - n(a\mu - c_1)(\chi(n(a\mu - c_1)))\right) / \left((\alpha + c_2)^2\chi \left(2B(n-1)(a(n+1)\kappa + 2c_2) + n(a\mu - c_1)(\chi(n(a\mu - c_1)))\right)^2\right)
\]

\[
> 0
\]

since \(2B(n-1)(a(n+1)\kappa + 2c_2) + n^2(a\mu - c_1)^2 > n(a\mu - c_1)\chi\) as one can easily verify.

\[
\frac{\partial \alpha_{PS}}{\partial B} = \frac{2n(a(n+1)\kappa + 2c_2)(a\mu - c_1)}{(\alpha + c_2)\chi \left(-2B(n-1)(a(n+1)\kappa + 2c_2) + n^2(a\mu - c_1)^2 - n(a\mu - c_1)\chi\right)^2} > 0.
\]

\[
\frac{\partial \alpha_{PS}}{\partial n} = -4B(a(n+1)\kappa + 2c_2) \left(2B(a(n+1)\kappa + 2c_2)(a(n-1)\kappa + (3n-2)c_2)(a\mu - c_1) + (a + 2c_2)n^2(a\mu - c_1)^3 + \chi \left(2Bc_2(a(n+3)\kappa + 2c_2) - (a + 2c_2)n(a\mu - c_1)^2 + 2Ba^2(n+1)\kappa^2\right)\right) / \left((\alpha + c_2)^2\chi \left(-2B(n-1)(a(n+1)\kappa + 2c_2) + n^2(a\mu - c_1)^2 - n(a\mu - c_1)\chi\right)^2\right)
\]

\[
> -4B(a(n+1)\kappa + 2c_2) \left(2B(a(n+1)\kappa + 2c_2)(a(n-1)\kappa + (3n-2)c_2)(a\mu - c_1) + n(a\mu - c_1) \left(2Bc_2(a(n+3)\kappa + 2c_2) + 2Ba^2(n+1)\kappa^2\right) + (a + 2c_2)n(a\mu - c_1)^2(n(a\mu - c_1) - \chi)\right) / \left((\alpha + c_2)^2\chi \left(-2B(n-1)(a(n+1)\kappa + 2c_2) + n^2(a\mu - c_1)^2 - n(a\mu - c_1)\chi\right)^2\right)
\]

\[
= - \frac{4B(a(n+1)\kappa + 2c_2)(a\mu - c_1)(2B(n-1)(a(n+1)\kappa + 2c_2) + n^2(a\mu - c_1)^2 - n(a\mu - c_1)\chi)}{(\alpha + c_2)\chi \left(-2B(n-1)(a(n+1)\kappa + 2c_2) + n^2(a\mu - c_1)^2 - n(a\mu - c_1)\chi\right)^2} < 0
\]
where the second inequality follows since $\chi > n(a\mu - c_1)$ and the last follows as $2B(n - 1)(a(n + 1)\kappa + 2c_2) + n^2(a\mu - c_1)^2 > n(a\mu - c_1)\chi$, proving the proposition.

\[\Box\]

Proof of Proposition 4.

Since,

\[
\frac{\partial^2 \Delta \Pi_{SW}^{PS}}{\partial B^2} = -\frac{(n - 1)^2(a(n + 2)\kappa + 2c_2)(a\mu - c_1)}{4B(n - 1)(a(n + 1)\kappa + 2c_2) + n^2(a\mu - c_1)^2} < 0,
\]

$\Delta \Pi_{SW}^{PS}$, which is equal to $\Delta \Pi_{SW}^{PS} - B$, is concave in $B$. The two roots of the equation $\Delta \Pi_{SW}^{PS} = B$ are 0 and $\bar{B}^{PS}$, which gives us the desired result when combined with concavity.

\[\Box\]

Proof of Corollary 1.

Since $\Delta \Pi_{SW}^{PS} = \Delta \Pi_{SW}^{PS} - B$, we will present the partial derivatives on $\Delta \Pi_{SW}^{PS}$.

\[
\frac{\partial \Delta \Pi_{SW}^{PS}}{\partial a} = \frac{1}{8(a(n + 1)\kappa + 2c_2)^3} \left[ \frac{8B\kappa c_2(n - 1)(a(n + 1)\kappa + 2c_2)}{n} 
+ (\chi - n(a\mu - c_1)) \left( \left( a(n + 1)\kappa + 2c_2 \right) (a(n + 2)\kappa + 2c_2) 
- (a(n + 1)(n + 2)\kappa + 2c_2) \mu(a\mu - c_1) \right) \left( 1 - \frac{n(a\mu - c_1)}{\chi} \right) 
+ 2c_2\mu(a\mu - c_1) \left( 1 + \frac{n(a\mu - c_1)}{\chi} \right) \right] > 0
\]

since $\chi = \sqrt{4B(n - 1)(a(n + 1)\kappa + 2c_2) + n^2(a\mu - c_1)^2} > n(a\mu - c_1)$. Thus $\Delta \Pi_{SW}^{PS}$ is increasing in $a$.

\[
\frac{\partial \Delta \Pi_{SW}^{PS}}{\partial \mu} = \frac{a}{4(a(n + 1)\kappa + 2c_2)^3} \left[ \frac{8B\mu c_2(n - 1)(a(n + 1)\kappa + 2c_2)}{n} 
+ (\chi - n(a\mu - c_1)) \left( \left( a(n + 1)\kappa + 2c_2 \right) (a(n + 2)\kappa + 2c_2) 
- (a(n + 1)(n + 2)\kappa + 2c_2) \mu(a\mu - c_1) \right) \left( 1 - \frac{n(a\mu - c_1)}{\chi} \right) 
+ 2c_2\mu(a\mu - c_1) \left( 1 + \frac{n(a\mu - c_1)}{\chi} \right) \right] > 0
\]

since $(a(n + 1)\kappa + 2c_2)(a(n + 2)\kappa + 2c_2) > (a(n + 1)(n + 2)\kappa + 2c_2(n - 1)) \mu(a\mu - c_1)$ as one can easily verify.

\[
\frac{\partial \Delta \Pi_{SW}^{PS}}{\partial c_1} = \frac{-(a(n + 2)\kappa + 2c_2)(2B(n - 1)(a(n + 1)\kappa + 2c_2) + n^2(a\mu - c_1)^2 - n(a\mu - c_1)\chi)}{2(a(n + 1)\kappa + 2c_2)^2} < 0.
\]

\[
\frac{\partial \Delta \Pi_{SW}^{PS}}{\partial c_2} = \frac{1}{4(a(n + 1)\kappa + 2c_2)^3} \left( \frac{4a(n - 1)\kappa B(a(n + 1)\kappa + 2c_2)}{n} 
- \frac{4B(n - 1)(a\mu - c_1)(a(n + 1)\kappa + 2c_2)(a(n + 2)\kappa + 2c_2)}{\chi} 
+ 2(a(n + 3)\kappa + 2c_2)(a\mu - c_1)(\chi - n(a\mu - c_1)) \right) > \frac{1}{4(a(n + 1)\kappa + 2c_2)^3} \left( \frac{4a(n - 1)\kappa B(a(n + 1)\kappa + 2c_2)}{n} 
+ 2(a(n + 2)\kappa + 2c_2)(a\mu - c_1) \right)
\]
\[\left(\chi - n(a\mu - c_1) - \frac{2B(n-1)(a(n+1)\kappa + 2c_2)}{\chi}\right)\]
\[= -\frac{1}{4(a(n+1)\kappa + 2c_2)^3}\left(\frac{4a(n-1)\kappa B(a(n+1)\kappa + 2c_2)n}{n} + 2(a(n+2)\kappa + 2c_2)(a\mu - c_1)\right)\]
\[\frac{2B(n-1)(a(n+1)\kappa + 2c_2) + n^2(a\mu - c_1)^2 - n(a\mu - c_1)\chi}{\chi}\]
\[< 0,\]
proving the desired result. We now present the partial derivatives on \(\hat{B}^{PS}\).

\[
\frac{\partial \hat{B}^{PS}}{\partial a} = \frac{2n^2\kappa(a\mu - c_1)(V + \bar{V})}{(n-1)(a\kappa + 2c_2)^3(a(n+1)\kappa + 2c_2)^2}
\]
where \(V = a^2\kappa^2(an(n+1)(n+2)\kappa(a\mu + c_1) + 2c_2(a\mu(n+2)(5n+3) + c_1(n-2)(n+1))) > 0\) and \(\bar{V} = 4a^2\kappa^2c_2^2(2c_2(3a\mu - c_1) + a\kappa(a\mu(7n+10) - c_1(n+4))) > 0\), so \(\hat{B}^{PS}\) is increasing in \(a\).

\[
\frac{\partial \hat{B}^{PS}}{\partial \mu} = \frac{4an^2(a\mu - c_1)(U + \bar{U})}{(n-1)(a\kappa + 2c_2)^3(a(n+1)\kappa + 2c_2)^2}
\]
where \(U = a^2\kappa^2(an(n+1)(n+2)\kappa(a\sigma^2 + c_1\mu) + 2c_2(a(2\kappa(n+3n+1) + \mu^2(n+2) + \sigma^2n^2) + c_1\mu(n-2)(n+1))) > 0\) and \(\bar{U} = 4c_2^2(a\kappa(3a(n+1)\kappa + (a\mu - c_1)\mu(n+4) + 2c_2) + 2c_2\mu(a\mu - c_1)) > 0\). Hence, \(\hat{B}^{PS}\) is increasing in \(\mu\).

\[
\frac{\partial \hat{B}^{PS}}{\partial c_1} = -\frac{4an^2\kappa(a(n+2)\kappa + 2c_2)(a\mu - c_1)}{(n-1)(a\kappa + 2c_2)^2(a(n+1)\kappa + 2c_2)} < 0,
\]
and
\[
\frac{\partial \hat{B}^{PS}}{\partial c_2} = -\frac{4an^2\kappa(a\mu - c_1)^2(a^2(2n^2 + 7n + 4)\kappa^2 + 2a\kappa c_2(4n+7) + 8c_2^2)}{(n-1)(a\kappa + 2c_2)^3(a(n+1)\kappa + 2c_2)^2} < 0,
\]
so \(\hat{B}^{PS}\) is decreasing in \(c_1\) and \(c_2\).

If \(c_2 = 0\), \(\hat{B}^{PS}\) reduces to \(\frac{2(n+2)(a\mu - c_1)^2}{a\kappa(n^2-1)}\), which is decreasing in \(n\) and \(\sigma\). In this case,

\[
\frac{\partial \Delta \Pi_{SW}^{PS}}{\partial n} = \frac{2Ba(n+1)\kappa(a\mu - c_1)(3-n)((a\mu - c_1)^2 + 2Ba(n+1)\kappa)}{2a(n+1)^3\kappa \sqrt{4Ba(n^2-1)\kappa + n^2(a\mu - c_1)^2}}
\]
where the second term in the numerator is negative and the first term is non-positive for \(n \geq 3\) while the denominator is positive. So, if \(c_2 = 0\), \(\Delta \Pi_{SW}^{PS}\) is decreasing in \(n\) for \(n \geq 3\). And finally,

\[
\frac{\partial \Delta \Pi_{SW}^{PS}}{\partial \sigma} = -\frac{\sigma(n+2)(a\mu - c_1)\left(2Ba(n^2-1)\kappa + n(a\mu - c_1)\left(n(a\mu - c_1) - \sqrt{4Ba(n^2-1)\kappa + n^2(a\mu - c_1)^2}\right)\right)}{2a(n+1)^2\kappa^2 \sqrt{4Ba(n^2-1)\kappa + n^2(a\mu - c_1)^2}} < 0,
\]
proving the desired result.

---

**Proof of Proposition 5.**

Let us define

\[
h(x) = a\mu - c_1 - (a(n+1)\kappa + 2c_2)x + \frac{B}{nx} + ax \int_{\frac{\delta}{\kappa\kappa}}^{\frac{\delta}{\kappa\kappa}} \phi^2 f(\phi) d\phi.
\] (13)
Farmer $j$’s optimal land allocation under price support when the target price is announced satisfies $h(x_j^{FS}) = 0$ as shown in (6). On the other hand, when we plug the optimal land allocation under price support in the case of the budget announcement into (13), we obtain

$$h(x_j^{PS}) = \frac{\chi - n(a\mu - c_1)}{2n(n-1)} + ax_j^{PS} \int_{a^n\phi_a^{PS}}^{\phi} \frac{\phi^2 f(\phi)}{\phi_a^{PS}} d\phi > 0.$$  

As a result, assuming concavity, i.e. the condition given in (7) holds, we have $x^{PS} < x^{FS}$.

**Proof of Proposition 6.**

$$\frac{\Delta \Pi^{FS}}{\Pi^{FS}_F} - \frac{\Delta \Pi^{CS}}{\Pi^{CS}_F} = \frac{\Delta \Pi^{PS}}{\Pi^{PS}_F} - \frac{\Delta \Pi^{CS}}{\Pi^{CS}_F}$$

$$= \frac{(a\mu - c_1)x^{FS} - a\kappa (x^{FS})^2}{(x^{FS})^2}$$

$$= \frac{n}{(x^{NI})^2 (a\kappa + c_2)}$$

$$= \frac{n}{(x^{NI})^2 (a\kappa + c_2)}$$

$$= \frac{n}{(x^{NI})^2 (a\kappa + c_2)}$$

$$< 0$$

where the fifth equality follows from the first order condition given in (5). Since $\frac{\Delta \Pi^{FS}}{\Pi^{FS}_F} < \frac{\Delta \Pi^{CS}}{\Pi^{CS}_F}$, we have $a^{FS} < 1$.

**Proof of Proposition 7.**

Follows from the fact that farmer $j$ solves the same optimization problem in the case of price and cost support interventions, as given in (3) and (9), when the budget is public information.

**Proof of Proposition 8.**

It is trivial that $x^{CS} < x^{CS}$. Moreover, we have

$$h(x_j^{CS}) = ax_j^{CS} \int_{a^n\phi_a^{CS}}^{\phi} \frac{\phi^2 f(\phi)}{\phi_a^{CS}} d\phi > 0,$$
resulting in $x^{C} < x^{CS}$ when combined with concavity.

Proof of Proposition 9.

From (10), it is trivial that $x^{NI} < x^{CS}$. Farmers’ expected profits under cost support when the unit subsidy is known is given as

$$\Pi_{\tilde{F}}^{CS} = \mathbb{E} \left[ p_0 x^{\tilde{CS}} \right] - \left( c_1 - \tilde{\Delta} c_1 \right) x^{\tilde{CS}} + c_2 \frac{\left( x^{\tilde{CS}} \right)^2}{n}$$

$$= \left( a\mu - c_1 + \tilde{\Delta} c_1 \right) x^{\tilde{CS}} - a\alpha \left( x^{\tilde{CS}} \right)^2 - c_2 \frac{\left( x^{\tilde{CS}} \right)^2}{n}.$$  \hspace{1cm} (14)

and the consumer surplus is $\Pi_{C}^{CS} = \frac{a\alpha}{2} \left( x^{\tilde{CS}} \right)^2$ as given in (1). Thus, we have

$$\Delta \Pi_{\tilde{F}}^{CS} = \frac{n(a\alpha + c_2)\Delta c_1 \left( 2(a\mu - c_1) + \Delta c_1 \right)}{(a(n+1)\alpha + 2c_2)^2} > 0,$$

$$\Delta \Pi_{C}^{CS} = \frac{a\alpha^2 \Delta c_1 \left( 2(a\mu - c_1) + \Delta c_1 \right)}{2(a(n+1)\alpha + 2c_2)^2} > 0.$$

Lastly,

$$\frac{\Delta \Pi_{\tilde{F}}^{CS}}{\Pi_{\tilde{F}}^{CS}} - \frac{\Delta \Pi_{C}^{CS}}{\Pi_{C}^{CS}} = \frac{\Delta \Pi_{\tilde{F}}^{CS}}{\Pi_{\tilde{F}}^{CS}} - \frac{\Pi_{C}^{CS}}{\Pi_{C}^{CS}}$$

$$= \frac{(a\mu - c_1 + \Delta c_1)x^{\tilde{CS}} - a\alpha \left( x^{\tilde{CS}} \right)^2 - c_2 \frac{\left( x^{\tilde{CS}} \right)^2}{n}}{(a\mu - c_1)x^{NI} - a\alpha \left( x^{NI} \right)^2 - c_2 \frac{\left( x^{NI} \right)^2}{n}} - \frac{a\alpha \left( x^{\tilde{CS}} \right)^2}{a\alpha \left( x^{NI} \right)^2}$$

$$= \frac{(a\mu - c_1 + \Delta c_1)x^{\tilde{CS}} - a\alpha \left( x^{\tilde{CS}} \right)^2 - c_2 \frac{\left( x^{\tilde{CS}} \right)^2}{n}}{(x^{NI})^2 (a\alpha + c_2) + a\alpha \left( x^{\tilde{CS}} \right)^2} - \frac{(x^{\tilde{CS}})^2}{(x^{NI})^2}$$

$$= \frac{nx^{\tilde{CS}}}{(x^{NI})^2 (a\alpha + c_2)} \left( a\mu - c_1 + \Delta c_1 - \frac{a(n+1)\alpha + 2c_2}{n} \right)$$

$$= 0$$

where the last equality follows from (10), proving the proposition.

Proof of Proposition 10.

Since $\Delta c_1 x^{\tilde{CS}} = B$, one can rewrite (14) as $\Pi_{\tilde{F}}^{CS} = (a\mu - c_1) x^{\tilde{CS}} - a\alpha \left( x^{\tilde{CS}} \right)^2 - c_2 \frac{\left( x^{\tilde{CS}} \right)^2}{n} + B$. Then, we obtain

$$\frac{\partial^2 \Delta \Pi_{CS}^{SW}}{\partial B^2} = - \frac{\sqrt{n} (a(n+1)\alpha + 2c_2)(a\mu - c_1)}{(4B (a(n+1)\alpha + 2c_2) + n(a\mu - c_1)^2)^{3/2}} < 0,$$

proving the concavity of $\Delta \Pi_{G}^{CS} = \Delta \Pi_{CS}^{SW} - B$. The two roots of the equation $\Delta \Pi_{CS}^{SW} = B$ are 0 and $B^{\tilde{CS}}$, which gives us the desired result when combined with concavity. Moreover,

$$B^{CS} - B^{\tilde{CS}} = \frac{2an(a\alpha - c_1)^2 (a(n+1)\alpha + 2c_2)}{(n-1)(a\alpha + c_2)^2 (a(n+1)\alpha + 2c_2)} > 0,$$
proving the proposition.

\[ x^{NI} < x^{CS} < x^{PS} < x^{PS}. \] (15)

Note that, keeping the expected government spending fixed, the total expected profit of farmers is given by \( \Pi_i = (\alpha \mu - c_1) x^i - \alpha (x^i)^2 - c_2 (x^i)^2 + \frac{a(\alpha \mu - c_1)}{2(\alpha + c_2)}, \) which is less than \( x^{NI}. \) That is, competition among farmers induces inefficient land allocation that is greater than the optimal amount. This, combined with (15) and concavity of the farmers’ expected profits, gives \( \Pi^P_S < \Pi^G_S < \Pi^C_S = \Pi^P_S. \) Since the consumer surplus under intervention \( i \) is given by \( \Pi^C = \frac{a(\alpha x^i)^2}{2} \), we have \( \Pi^C_S = \Pi^G_S < \Pi^C_S < \Pi^C. \)

\[ \Pi = \text{total expected profit of farmers} \]

Proof of Proposition 12.
Keeping the expected government expenditure fixed, the social welfare under intervention \( i \) is given by \( \Pi^S = \Pi^P + \Pi^C = (\alpha \mu - c_1) x^i - \alpha (x^i)^2 - c_2 (x^i)^2 + B. \) The maximizer of the social welfare function is given by \( x^{**} = \frac{n(\alpha \mu - c_1)}{\alpha + c_2}. \) Now, \( x^{CS} < x^{**} \) if and only if \( B < \frac{\alpha(\alpha \mu - c_1)^2}{2(\alpha + c_2)^2}, \) under which condition \( \Pi^C_S = \Pi^P_S < \Pi^G_S \) due to (15) and concavity of the social welfare function. On the other hand, \( x^{**} < x^{CS} \) if and only if \( B > \frac{an^2(\alpha \mu - c_1)^2}{(n-1)(\alpha \mu + c_2)^2}, \) resulting in \( \Pi^P_S < \Pi^C_S < \Pi^G_S = \Pi^P_S \) by the same reasoning.

Proof of Proposition 13.
The change in the amount of land allocated to production is given by

\[ x^{Y, E} - x^{NI} = \frac{n \mu \delta - 1)((n + 1)(a \sigma^2 + c_1 \mu) + 2c_2 - \delta \mu(n + 1)(\alpha \mu - c_1))}{(a + 1)n \kappa + 2c_2)(a + 1)\kappa + 2c_2} + 2c_2}. \]

The denominator is positive and the numerator is positive if and only if \( \delta < \frac{(n+1)(a \sigma^2 + c_1 \mu) + 2c_2}{(a + 1)n \mu(a \mu - c_1)}. \) Furthermore, the change in the expected total supply is calculated as

\[ \delta x^{Y, E} - \delta x^{NI} = \frac{n \mu (a \sigma^2 + c_1 \mu)(a \mu - c_1)(\alpha \mu - c_1)(\alpha \mu - c_1)(\alpha \mu - c_1)}{(a + 1)n \kappa + 2c_2)(a + 1)\kappa + 2c_2} > 0 \]

since \( \delta > 1. \)

Note that both \( \Delta \Pi^E_C \) and \( \Delta \Pi^E_S \) are 0 when \( \delta = 1. \) We have

\[ \frac{\partial \Delta \Pi^E_C}{\partial \delta} = \frac{an^2 (a \sigma^2 + c_1 \mu)(a \mu - c_1)(\alpha \mu - c_1)}{(a(n + 1) \kappa + 2c_2)^2} > 0 \]

and

\[ \frac{\partial \Delta \Pi^E_S}{\partial \delta} = \frac{an(c \delta - 1)(a \sigma^2 + c_1 \mu)(a \mu - c_1)(\alpha \mu - c_1)}{(a(n + 1) \kappa + 2c_2)^2} > 0. \]

As a result, \( \Delta \Pi^E_C > 0 \) and \( \Delta \Pi^E_S > 0 \) for \( \delta > 1. \)

Lastly, if \( c_2 = 0, \) \( \Delta \Pi^E_P \) reduces to \( \frac{n \mu (\delta - 1)(a \sigma^2 + c_1 \mu)(a \mu - c_1)(\alpha \mu - c_1)}{(a(n + 1)^2 \kappa)^2} > 0. \) We prove the last part of the proposition with the following lemma.
Lemma 1. Let $\rho = \sigma / \mu$. Then if $\rho < \sqrt{\delta}$, $a > c_1 \mu (\delta + 1)$, $c_2 > a \kappa (a \kappa + c_2) - \kappa (a \kappa + c_2) > 0$.

\[
c_2 > \frac{a \kappa (a \kappa + c_2)}{(a(n+1)\kappa + 2c_2)^2} < 0
\]

and

\[
n > \frac{(a(n+1)\kappa + 2c_2)^2}{a(n+1)\kappa + 2c_2} > 0
\]

if and only if $(a \kappa + c_2) > (a(n+1)\kappa + 2c_2)^2$, which reduces to $n > (a \kappa + c_2)^2 > 0$.

Proof: We have

\[
\Delta \Pi_{\rho}^{\kappa} = n \left( \frac{(a \kappa + c_2)^2 - (a(n+1)\kappa + 2c_2)^2}{a(n+1)\kappa + 2c_2} \right) < 0
\]

if and only if $n > (a \kappa + c_2)^2 > 0$.

Moreover, (19) is satisfied if and only if $a \kappa > c_1 \kappa$. This can be reduced to $a > \frac{c_1 \mu (\delta + 1)}{\delta \mu^2 - \sigma^2}$ assuming $\kappa > \kappa \mu$, which is satisfied if and only if $\rho < \sqrt{\delta}$, proving the lemma.

Thus, in the parametric region described in Lemma 1, farmers’ expected profits decrease due to the yield enhancement intervention.

\[\square\]

Proof of Proposition 14.

We have

\[
\frac{\Delta \Pi_{\rho}^{\kappa}}{\Pi_{\rho}^{\kappa}} - \frac{\Delta \Pi_{\kappa}^{\rho}}{\Pi_{\kappa}^{\rho}} = -\frac{c_2 \mu^2 (\delta^2 - 1)(a \kappa + c_2)^2 (a(n+1)\kappa + 2c_2)^2}{(a \kappa + c_2)^1 (a(n+1)\kappa + 2c_2)^2} < 0,
\]

resulting in $\alpha^{\kappa} < 1$. Moreover,

\[
\frac{\partial \alpha^{\kappa}}{\partial n} = -\frac{4a(\delta + 1)^2 \mu^2 \kappa c_2^2 (a \kappa + c_2)^2 (a(n+1)\kappa + 2c_2)^2}{(a \kappa + c_2)^1 (a(n+1)\kappa + 2c_2)^2} < 0
\]
where \( T = a^2(n+1)\kappa \hat{k} \left( (a\mu(\delta + 1) - 2c_1)(a(n+1)\sigma^2 + 4c_2) + c_1\mu(n+1)(2a\delta \mu - c_1(\delta + 1)) \right) + 4c_2^3 \left( \mu(a\mu(\delta + 1) - c_1)(\alpha(2\delta + 1) - c_1(\delta + 1)) + a\sigma^2(a\mu(\delta + 1) - 2c_1) \right) \), and

\[
\frac{\partial \alpha^{VE}}{\partial c_1} = \frac{2a\mu(\delta + 1)(a\mu - c_1)(a\delta \mu - c_1)kc_2(a(n+1)\kappa + 2c_2)^2(a(n+1)\hat{k} + 2c_2)^2}{(a\kappa + c_2)^T^2} > 0,
\]

so \( \alpha^{VE} \) is decreasing in \( n \) and increasing in \( c_1 \). Lastly, if \( c_2 = 0 \), \( (20) \) reduces to 0, proving the proposition.

\[\square\]

**Proof of Proposition 15.**

We have

\[
\frac{\partial \Delta \Pi_{SW}^{VE}}{\partial \sigma} = \alpha \sigma \left( \frac{(a\mu - c_1)(a(n+1)(n+2)\kappa + 2c_2n)}{(a(n+1)\kappa + 2c_2)^3} - \frac{(a\delta \mu - c_1)(a(n+1)(n+2)\hat{k} + 2c_2n)}{(a(n+1)\hat{k} + 2c_2)^3} \right).
\]

Let \( X_1 = a(n+1)(n+2)\kappa + 2c_2n, Y_1 = a(n+1)\kappa + 2c_2, X_2 = a(n+1)(n+2)\hat{k} + 2c_2n, \) and \( Y_2 = a(n+1)\hat{k} + 2c_2 \).

Hence, \( \frac{\partial \Delta \Pi_{SW}^{VE}}{\partial \sigma} < 0 \) if and only if \( c_1 (\sqrt{X_1Y_2^3} - \sqrt{X_2Y_1^3}) > a\mu \left( \sqrt{X_1Y_2^3} - \delta \sqrt{X_2Y_1^3} \right) \). As one can easily verify, \( X_1Y_2 > X_2Y_1^3 \), so the condition can be reduced to \( c_1 > a\mu \sqrt{X_1Y_2^3} \sqrt{X_2Y_1^3} \). Note that the right hand side is less than \( a\mu \), thus the assumption \( a\mu > c_1 \) is not violated.

\[\square\]

**References**


